Experimental report

04/01/2018

Proposal:	**4-02-488**	**Council:**	10/2016

Title: Magnetic studies on LSCO superconductor close to the underdoped quantum critical point

Research area: Physics

This proposal is a new proposal

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Samples:
La(1.95)Sr(0.05)CuO(4)
La(1.92)Sr(0.08)CuO(4)

Instrument	Requested days	Allocated days	From	To
THALES	7	6	14/02/2017	20/02/2017

Abstract:

In the quest to explain the origin of high temperature superconductivity (HTSC) much attention has been given to the interplay between magnetism and superconductivity in cuprate superconductors especially LSCO. We propose a study of the extreme underdoped region (3% < x < 10%) at the insulator-superconductor boundary also denoted the quantum critical point (QCP). Our aim is to study the magnetic stripe order in samples with different doping by applying magnetic fields which will suppress superconductivity. We will start with two crystals, 5% and 8% Sr doping, and will latter continue with other samples covering the underdoped region. This type of a systematic study of low magnetic fluctuations and a possible correspondence between the QCP and a magnetic quantum phase transition (QPT) has the potential to reveal important insights on the magnetic properties of cuprates which will improve our understanding of HTSC.

A study of low-energy spin excitations in LSCO with $x = 0.08$, at Thales

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The purpose of this experiment was to characterize the static stripes and the low-lying stripy fluctuations and to study their behavior under applied magnetic field.

The sample

The sample is a LSCO single crystal with doping value $x = 0.08$. It has been characterized by means of VSM measurement and X-ray Laue backscattering, the results pointing to a high quality sample. It has a critical temperature of 21.5 K which is an indication that the strontium doping value is very close to the assumed $x = 0.08$. The dimensions of the crystal are as follows: cylindrical shape with length 2.3 cm, diameter 0.5 cm and mass $\sim$5 g.

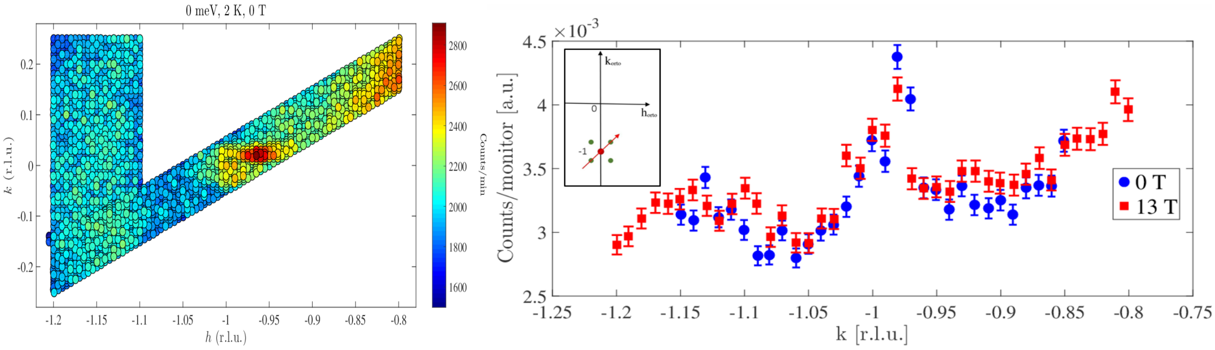
The results 1) Elastic measurements

The first measurement performed was an elastic grid scan which was intended as a check of the peaks positions and background levels. When scanning around the (-1 0 0) position no elastic signal was detected whatsoever (see Figure 1a). The high intensity peak at position (-0.97 0 0)) is structural and comes from some, unfortunately aligned, impurity grain in the sample and disappears completely when scanning the equivalent (0 -1 0) reflection. Numerous studies from the literature point to an enhancement of the static magnetic order by application of a magnetic field in samples with a wide doping range [Lake et al., 2002, Chang et al., 2008, Khaykovich et al., 2005]. An applied field of 13 T, however, had no significant effect in the case of our sample (see Figure 1b).

2) Inelastic measurements

All evidence, from the literature, points to either an enhancement of the low-energy fluctuations in LSCO samples with $x = 0.105$ [Chang et al., 2007], $x = 0.145$ [Christensen et al., 2011] and $x = 0.16$ [Lake et al., 2001] or no effect at all in LSCO samples with $x = 0.12$ [Rømer et al., 2013]. We set out to confirm this behavior in our samples, but what we measured turned out to be the opposite. Figure 2 shows a field suppression of the low energy (0.6 meV was chosen as an example) magnetic fluctuations.

The same scans, in a 13 T magnetic field and in no applied field, were then repeated for different energy transfers and the resulted overview is shown in Figure 3a, for measurements performed at 1.7 K, and in Figure 3b for measurements performed at 22 K. The 22 K temperature was chosen in order to probe the normal state, for it is slightly higher than the critical superconducting temperature. Better data is needed in order to make a quantitative analysis of this effect, especially in the normal state. Nonetheless, there is a clear field suppression of the low-energy magnetic fluctuations up to 1.5 meV in the superconducting state.



(a)

(b)

Figure 1: **(a)** Elastic grid scan measured on our LSCO with $x = 0.08$ sample at 1.7 K. **(c)** Superimposed diagonal scans taken in zero field (blue) and in a 13 T applied magnetic field perpendicular on the a-b plane (red). The direction of the scan is indicated in the left-hand side insert.

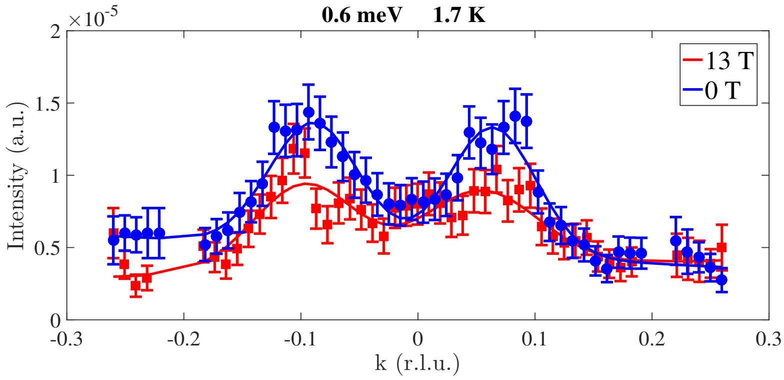
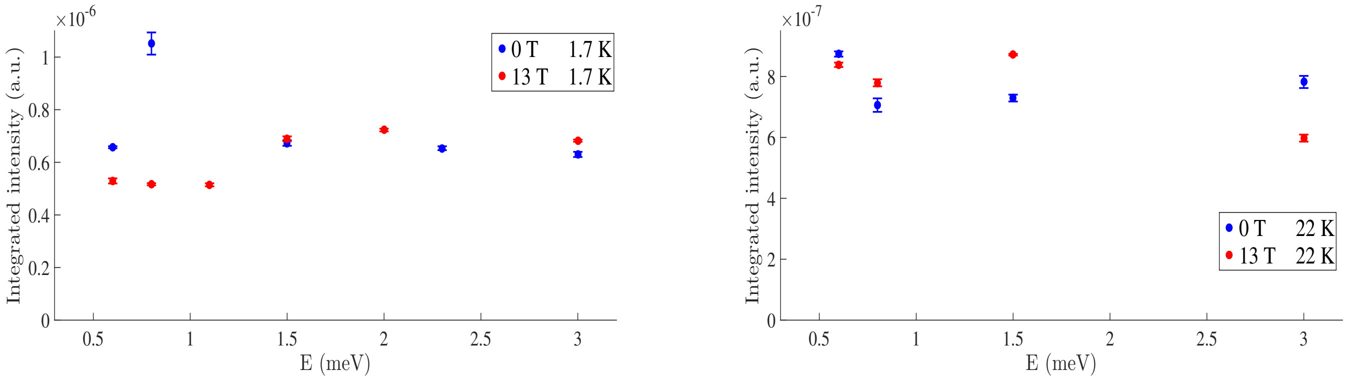


Figure 2: Inelastic neutron scattering data taken in a 13 T applied magnetic field (red) and without applied magnetic field (blue), at 1.7 K, with a 0.6 meV energy transfer.

3) Discussion

The fact that we observe no elastic signal could indicate that, in the underdoped region of the LSCO phase diagram, it is not the same ordering phenomena that generates the static and dynamic stripes.

The magnetic field suppression of the low energy stripy fluctuations is the most interesting finding so far. Contrary to all other experiments reported in the literature, the applied field causes a spin gap to open in our $La_{2-x}Sr_xCuO_4$ with $x = 0.08$ sample. More work is needed before a full understanding of the behavior of the underdoped LSCO samples in filed can be achieved. The next step will be acquiring better data in order to make a quantitative description of the suppression effect. Further on, more samples, with doping in the $0.055 < x < 0.09$ range should be studied in neutron scattering experiments so that a better understanding of the relationship between magnetism and superconductivity in the underdoped region of the phase diagram could be accomplished. For comparison, samples outside the superconducting regime, $x < 0.055$, should also be analyzed.



(a) **(b)**

Figure 3: Fitted integrated intensity as a function of energy transfer and applied magnetic field. The measurements were taken at **(a)** 1.7 K and **(b)** 22 K.

Bibliography

[Chang et al., 2008] Chang, J., Niedermayer, C., Gilardi, R., Christensen, N., Rønnow, H., McMorrow, D., Ay, M., Stahn, J., Sobolev, O., Hiess, A., et al. (2008). Tuning competing orders in $La_{2-x}Sr_xCuO_4$ cuprate superconductors by the application of an external magnetic field. *Physical Review B*, 78(10):104525.

[Chang et al., 2007] Chang, J., Schnyder, A., Gilardi, R., Rønnow, H., Pailhes, S., Christensen, N. B., Niedermayer, C., McMorrow, D., Hiess, A., Stunault, A., et al. (2007). Magnetic-field-induced spin excitations and renormalized spin gap of the underdoped $La_{1.895}Sr_{0.105}CuO_4$ superconductor. *Physical review letters*, 98(7):077004.

[Christensen et al., 2011] Christensen, B., Chang, N., Razzoli, J., Bator, E., Niedermayer, M., Lefmann, K., Ronnow, M., Mcmorrow, F., Schneidewind, D., Link, A., et al. (2011). Magnetic field-induced closure of the spin excitation gap near optimal doping in $La_{2-x}Sr_xCuO_4$. *Journal of the Physical Society of Japan*, 80(Suppl. B):SB030.

[Khaykovich et al., 2005] Khaykovich, B., Wakimoto, S., Birgeneau, R., Kastner, M., Lee, Y., Smeibidl, P., Vorderwisch, P., and Yamada, K. (2005). Field-induced transition between magnetically disordered and ordered phases in underdoped $La_{2-x}Sr_xCuO_4$. *Physical Review B*, 71(22):220508.

[Lake et al., 2001] Lake, B., Aeppli, G., Clausen, K., McMorrow, D., Lefmann, K., Hussey, N., Mangkorntong, N., Nohara, M., Takagi, H., Mason, T., et al. (2001). Spins in the vortices of a high-temperature superconductor. *Science*, 291(5509):1759–1762.

[Lake et al., 2002] Lake, B., Rønnow, H., Christensen, N., Aeppli, G., Lefmann, K., McMorrow, D., Vorderwisch, P., Smeibidl, P., Mangkorntong, N., Sasagawa, T., et al. (2002). Antiferromagnetic order induced by an applied magnetic field in a high-temperature superconductor. *Nature*, 415(6869):299–302.

[Rømer et al., 2013] Rømer, A. T., Chang, J., Christensen, N. B., Andersen, B., Lefmann, K., Mähler, L., Gavilano, J., Gilardi, R., Niedermayer, C., Rønnow, H. M., et al. (2013). Glassy low-energy spin fluctuations and anisotropy gap in $La_{1.88}Sr_{0.12}CuO_4$. *Physical Review B*, 87(14):144513.